



Ideas & Chemistry

February 11, 2020

Development of Hollow Fiber Membrane for Brine Concentration

TOYOBO CO.,LTD.

Membrane Business Development Department

Takahito Nakao

Outline

- Brief introduction of Toyobo's current membrane business
- Development of membrane for brine concentration and its application

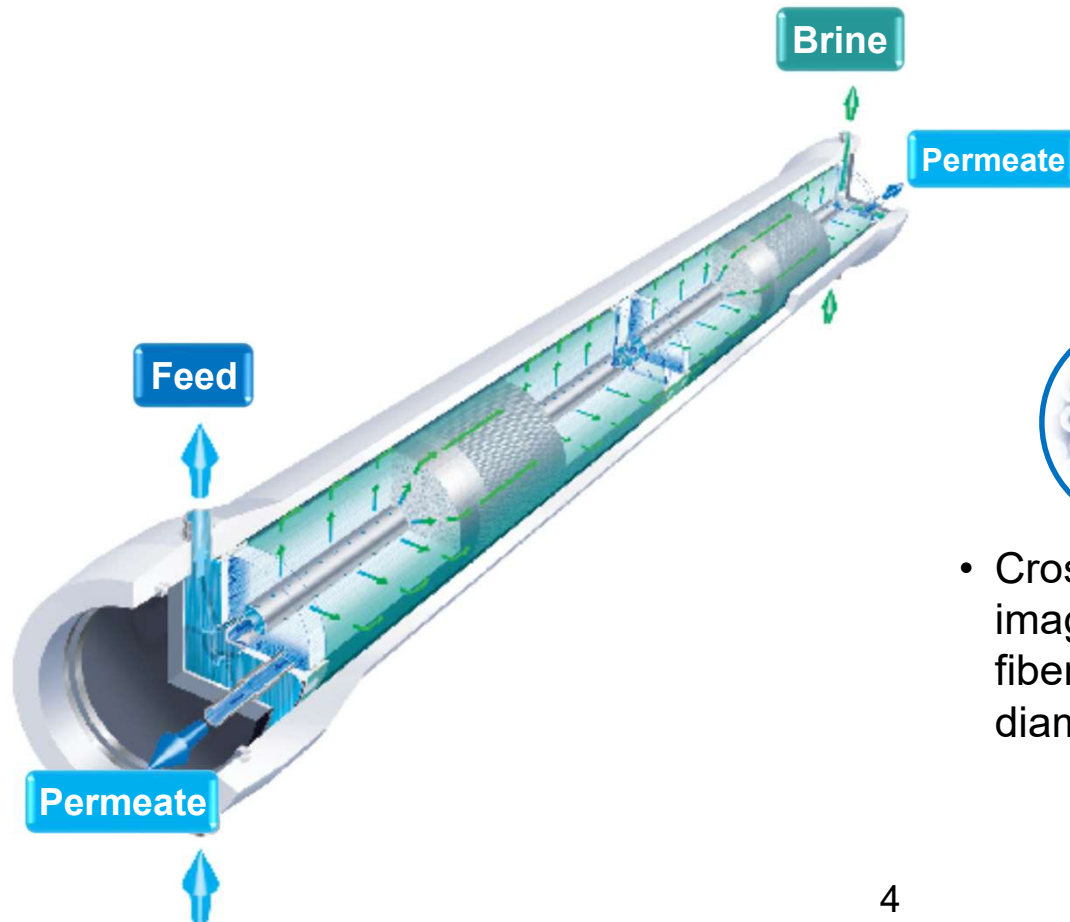
Outline

- Brief introduction of Toyobo's current membrane business
- Development of membrane for brine concentration and its application

About Toyobo's membrane

Brand name : HOLLOSEP®

- **Type:** Hollow Fiber RO membrane
- **Membrane Material:** Cellulose Tri-Acetate (CTA)
- **Application:** Seawater Desalination

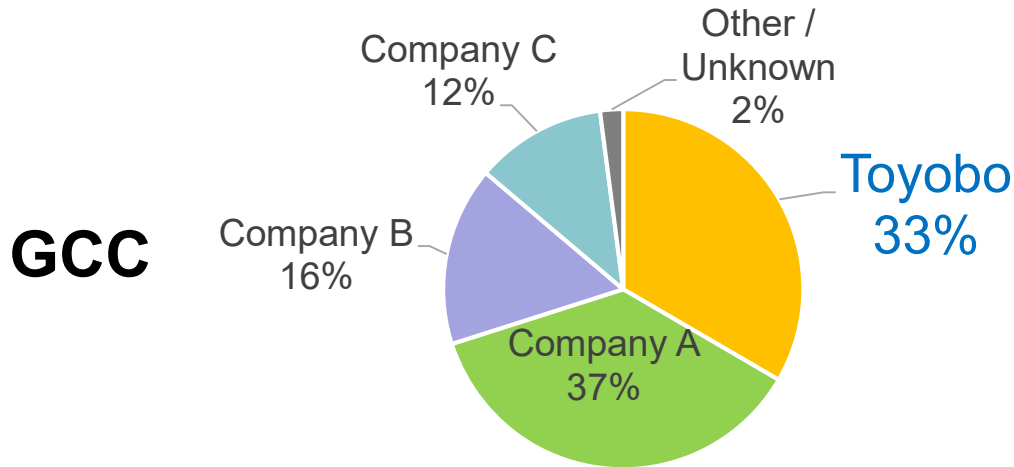


- Cross section image of hollow-fibers (fiber diameter: 150 μ m)

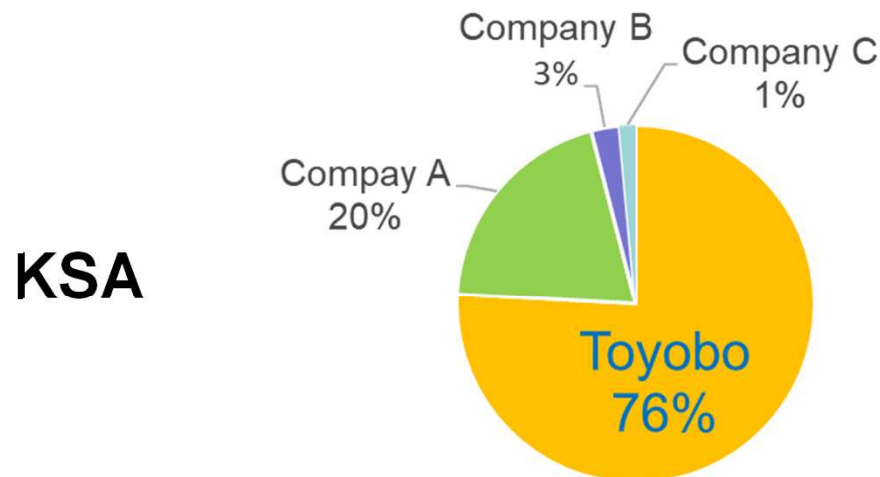
- Millions of hollow fibers are wound into the module construction by a cross winding

Toyobo is the leading RO supplier in the region

Market share by desalination capacity by top RO manufacturers



- 33% of desalination water in the GCC are produced using Toyobo membranes



- 76% of desalination water in KSA are produced using Toyobo membranes

Source: DesalData, Toyobo and Amane Advisors analysis

Note: * Operating SWRO plant with capacities over 30,000 m³/d since 1988

Numerous successful applications in the Middle East

Recent projects

Retrofit projects

Our references in the Middle East

Haql (Saudi Arabia)

Capacity: 4,400m³/day
Start year: 1989

Duba (Saudi Arabia)

Capacity: 4,400m³/day
Start year: 1989

Yanbu (Saudi Arabia)

Capacity: 128,000m³/day
Start year: 1998

Yanbu (Saudi Arabia)

Capacity: 50,400m³/day
Start year: 2006

Rabigh (Saudi Arabia)

Capacity: 218,000m³/day
Start year: 2008

Rabigh (Saudi Arabia)

Capacity: 109,000m³/day
Start year: 2015

Jeddah (Saudi Arabia)

Capacity: 113,600m³/day
Start year: 1989, 1994

Jeddah RO3 (Saudi Arabia)

Capacity: 260,000m³/day
Start year: 2013

Manifa (Saudi Arabia)

Capacity: 27,000m³/day
Start year: 2012

Ras Al Khair (Saudi Arabia)

Capacity: 345,000m³/day
Start year: 2014

Al Jubail (Saudi Arabia)

Capacity: 85,000m³/day (90,900m³/day)
Start year: 2007

AD DUR (BAHRAIN)

Capacity: 45,500m³/d
Start year: 2005

Al Birk (Saudi Arabia)

Capacity: 2,200m³/day
Start year: 2001

Shuqaiq (Saudi Arabia)

Capacity: 240,000m³/day
Start year: 2010

Overall
Capacity:
1,642,500
m³/day

Outline

- Brief introduction of Toyobo's current membrane business
- Development of membrane for brine concentration and its application

Key takeaways

- 1 The Brine Concentration (BC) market is growing rapidly**, driven by a number of economical, regulatory, environmental, and social factors
- 2 Conventional thermal membrane and crystallization technologies are very complex and extremely energy-intensive**
- 3 Our unique hollow-fiber CTA membrane is capable to concentrating brines up to 20% NaCl with less energy than existing technologies**
- 4 Our membrane applies solutions of equal salt concentrations to two distinct sides** (Bore and Shell), requiring a small hydraulic pressure to push water through the membrane
- 5 Using Toyobo's membranes can lead to reduced pumping requirement and deliver energy savings of 70% or more** compared to conventional thermal BC processes
- 6 Our membranes are have unique advantages to minimize the risks of biofouling and ensure stable operations**

The global BC market drivers

There are a number of key factors leading to the increasing adoption of BC technologies globally

Tightening regulations

Regulations are tightening and better enforced to prevent industrial users to minimize discharge of polluted wastewater

Limited disposal sites

Some areas have **limited access to suitable brine disposal sites or facilities**, leading to a high cost of water transport

Water scarcity

Water scarcity is intensifying in various parts of the world, **requiring industries to reuse more water**

Increasing industrialization

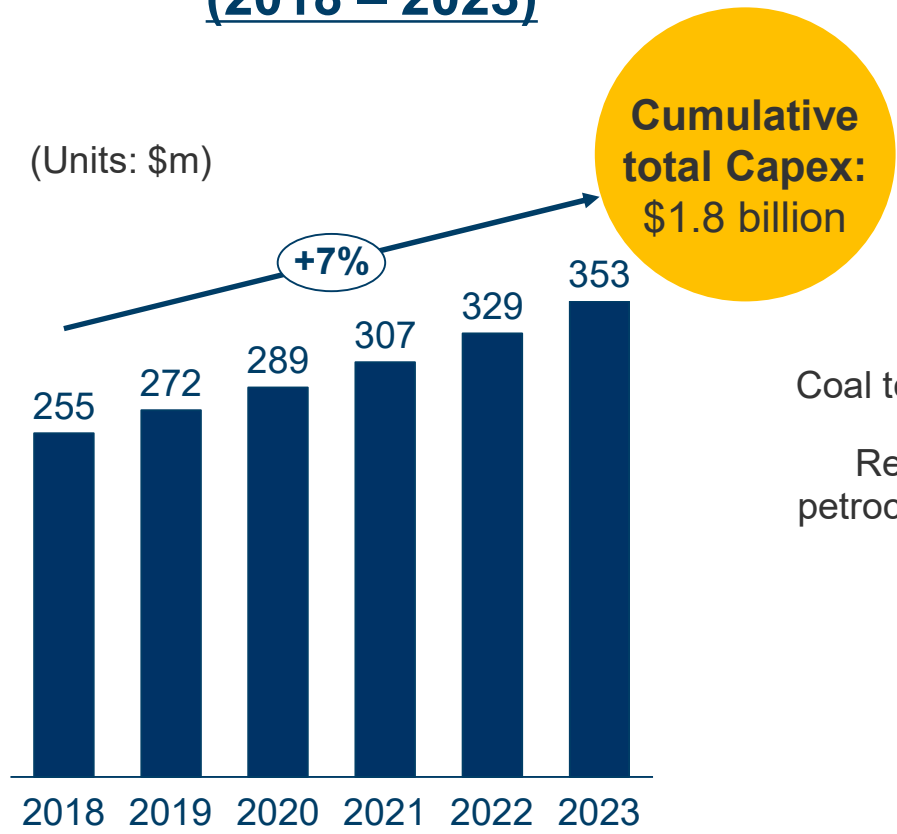
Increasing industrialization especially in developing countries resulting in **larger volumes of difficult to treat wastewater' residuals**

Reputation and public acceptance

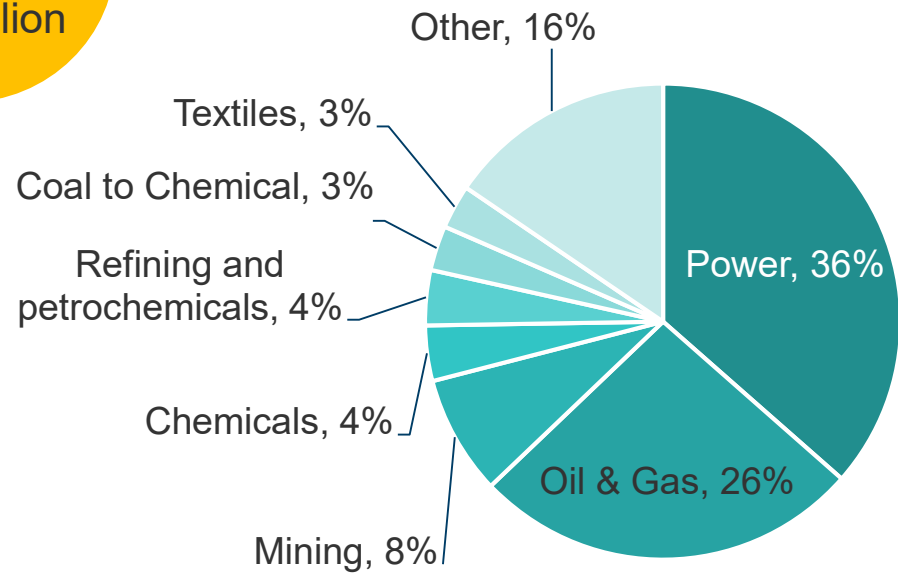
Many international companies are trying to “go green” to **ensure public acceptance to their businesses**

Large and fast-growing global BC market potential

Estimated BC/ ZLD market (2018 – 2023)



Cumulative BC / ZLD market (2018 – 2023)

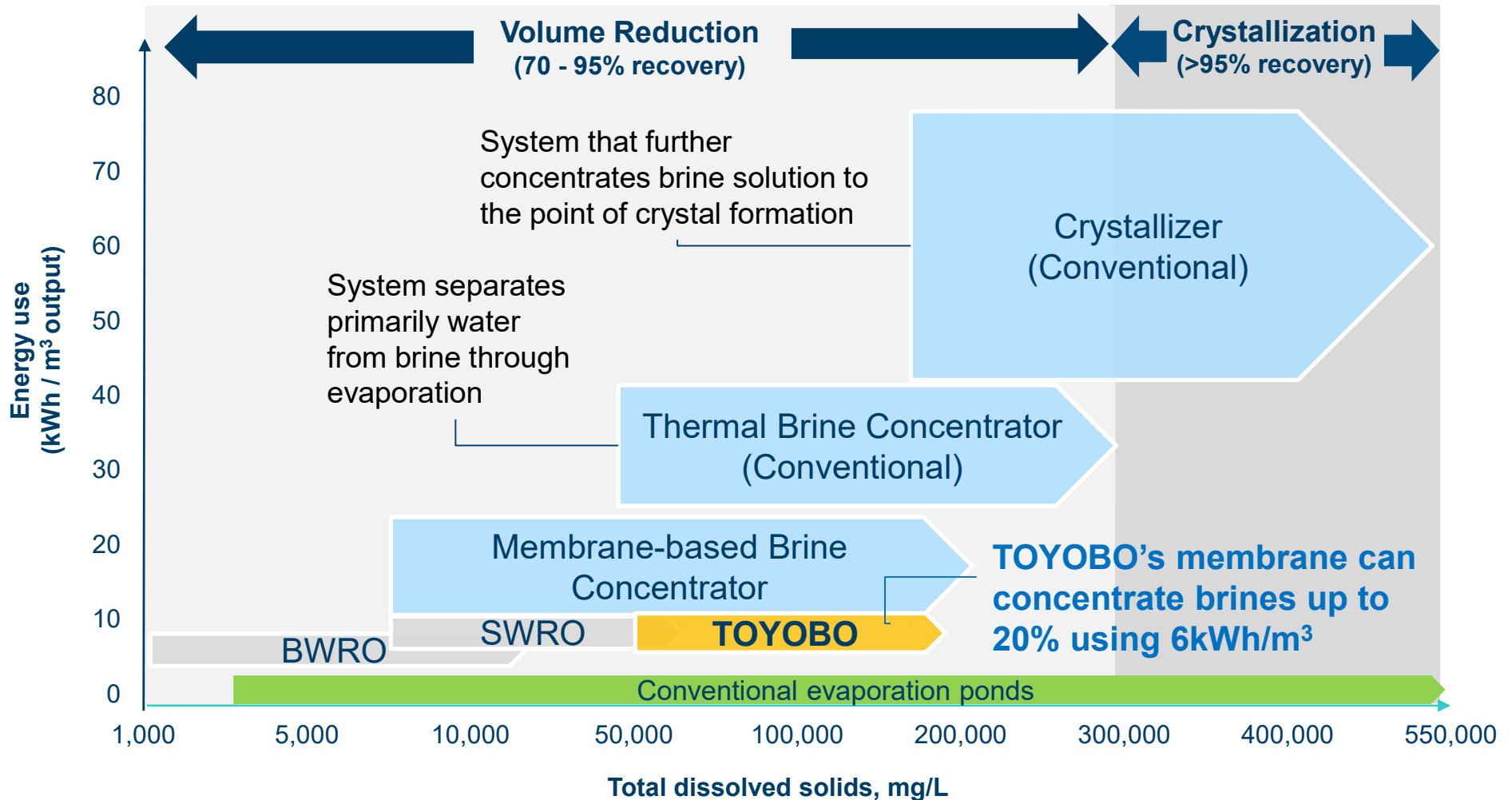


NOTE: Average annual system Capex for brine concentrators and crystallizers
Sources: GWI, Amane Advisors



Membranes are energy efficient BC technology

Energy intensities of BC/ ZLD processes



Note: Low-grade waste heat is not included in the energy consumption
Sources: GWI, Amame Advisors



Energy consumption comparison

	Technology	Maximum concentration	Energy consumption (kWh/m ³)	Resistance to scaling & fouling
Current Technology	Thermal	Saturated concentration	30~40	✓
New Technology	TOYOBO's BC	>20%	6	
	Electrodialysis	<18%	20	
	Disc tube RO	<12%	15	✓
	Ultra high pressure RO	<12%	15	

Applications of TOYOBO's membranes

TOYOBO's BC hollow fiber membrane process can:

- 1 **Reduce CAPEX and OPEX** in thermal evaporator and crystallizer ZLD systems
- 2 **Minimize the volumes** of difficult-to-treat wastewaters
- 3 **Deliver higher recovery** for desalination
- 4 **Increase wastewater reuse rates** for various industries
- 5 **Recover valuables** from wastewater

Toyobo's hollow-fiber CTA membrane

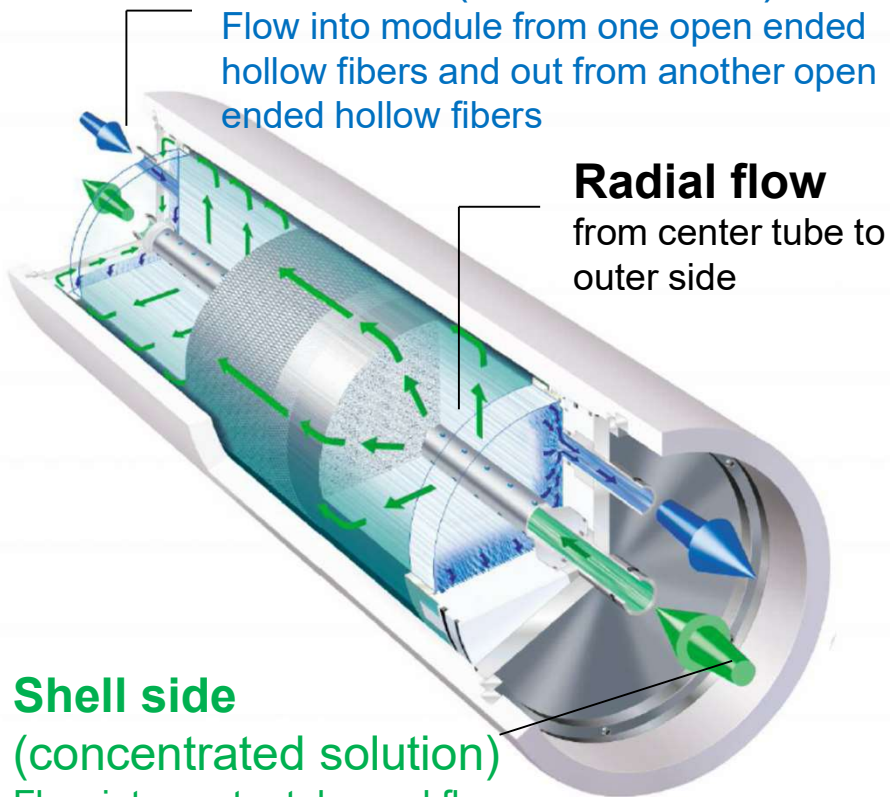
Membrane module structure

Bore side (dilute solution)

Flow into module from one open ended hollow fibers and out from another open ended hollow fibers

Radial flow

from center tube to outer side



Shell side

(concentrated solution)

Flow into center tube and flow uniformly and radially between hollow fibers, thanks to our cross wound configuration

Product specification

- **Material:** Cellulose Triacetate (CTA)
- **Diameter:** 280 mm
- **Length:** 1.4 m
- **Surface area:** 600 m²

Feedwater Requirement

- **pH :** 3-8
- **Temperature :** 5-40 °C
- **Pretreatment:** Colloids and suspended solids should be removed before BC membrane

NaCl Concentration by stage (feed and final %)	Flux (LMH)
7% → 10%	0.7
10% → 15%	0.3
15% → 20%	0.2

For RO reject at 7% NaCl

Advantages of TOYOBO's BC membranes

TOYOBO's membranes enable more stable, effective and energy efficient Brine Concentration

- ✓ **Only supplier of Hollow Fiber CTA membranes**
- ✓ **Proven commercial applications** in key industries
- ✓ **Capable of achieving higher concentration levels** (20% NaCl) using less energy (7MPa) than conventional RO (10 – 12% NaCl using 10MPa)
- ✓ **>70% energy savings** compared to a typical thermal BC process, and **>40%** compared to membrane-based BC process
- ✓ **Chlorine-tolerant membrane material** allowing direct chlorine injection to minimise biological fouling
- ✓ **No need for draw solution** like Forward Osmosis
- ✓ **High membrane surface area** for efficient operations and reduced fouling
- ✓ **Greater pressure resistance**, enabling applications for various usages

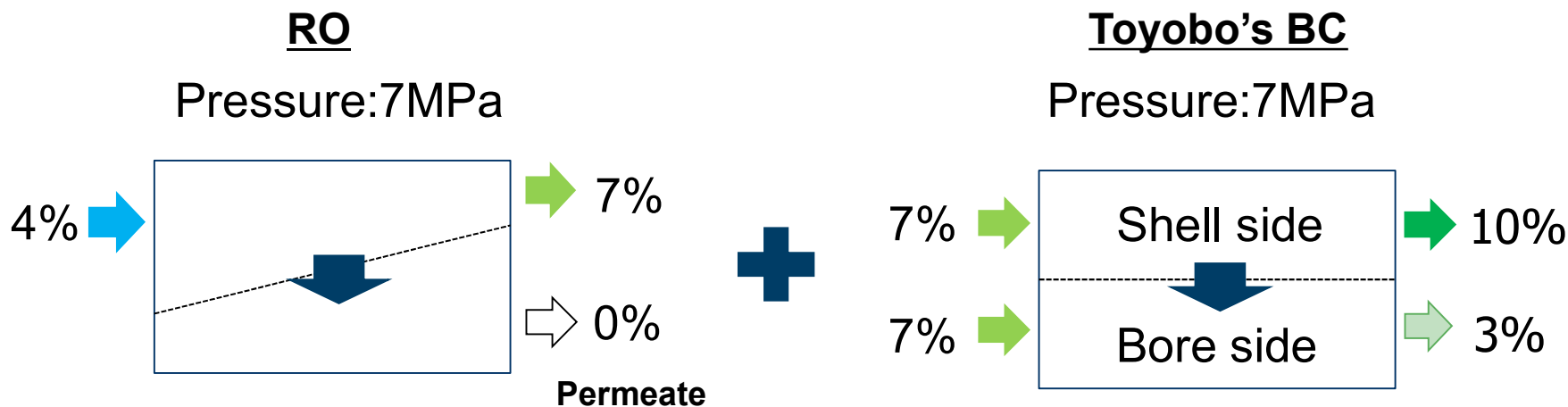
Toyobo's BC process mechanism

The same concentrated solutions are applied to both shell side and bore side and a certain pressure is applied to one side, **the same osmotic pressure difference as applied hydraulic pressure** can be obtained

Higher Concentration rate than RO membrane is available

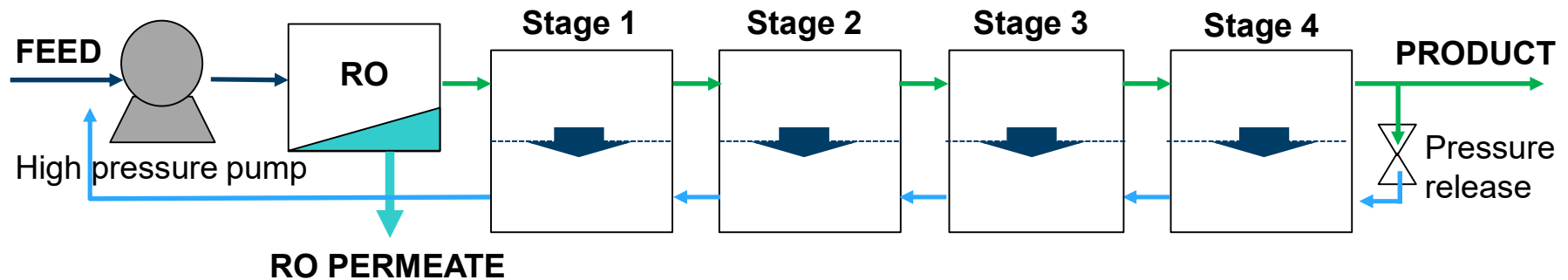
Concept of Toyobo's BC process

(% in NaCl)

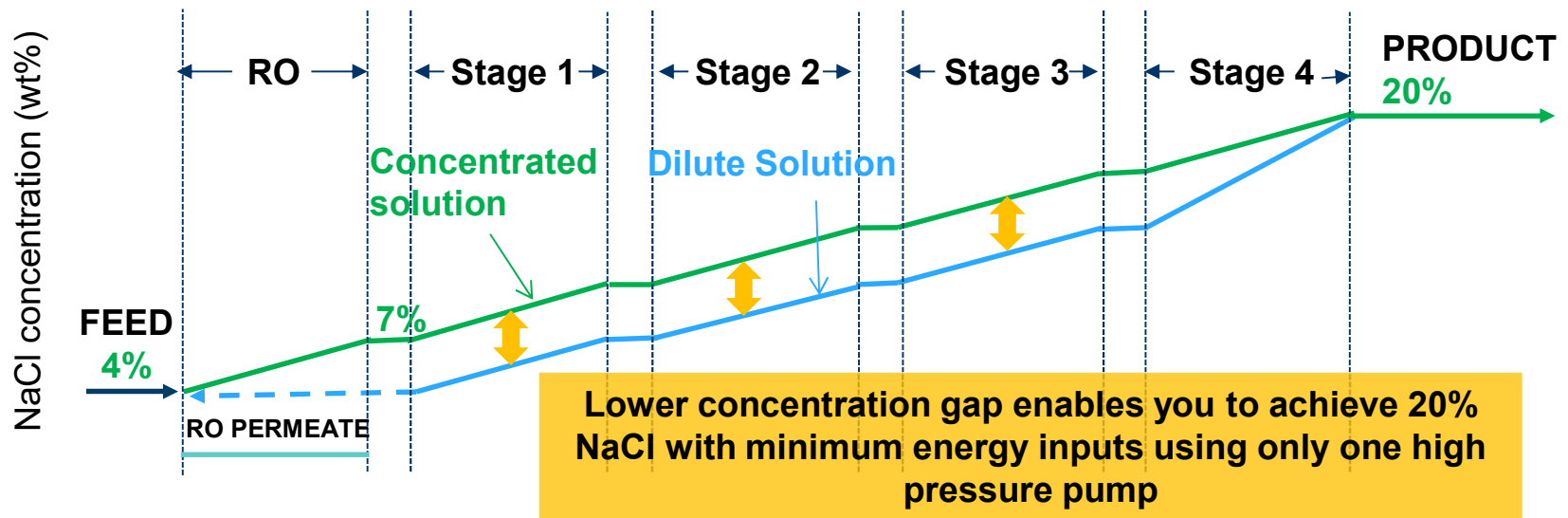


Energy-efficient process using only one high pressure pump

Toyobo BC Process



Concentration change in series arrangement



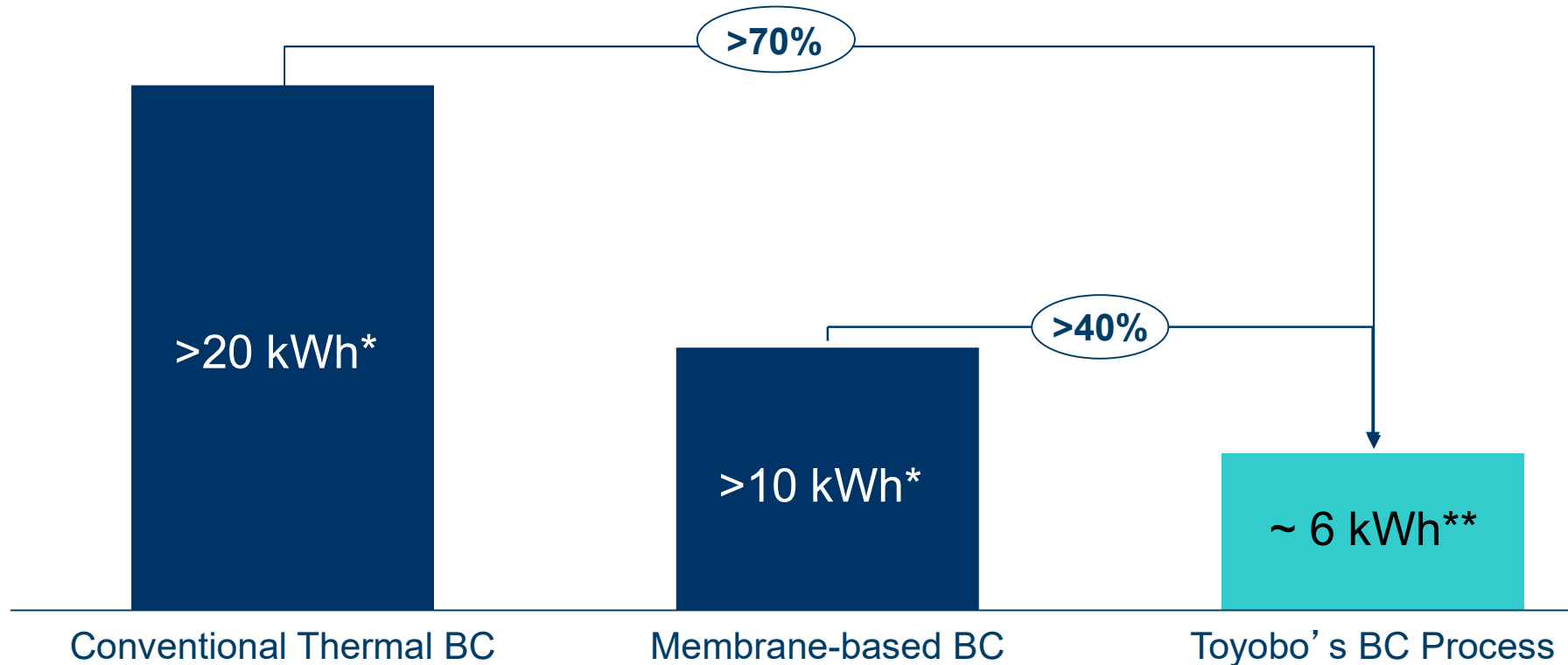
NOTE:

Higher concentration and continuous operation are available; 17
The number of stage varies depending on required concentration.



Superior Energy Savings

Reported typical energy requirement for m³ of product water to achieve 20% NaCl



NOTE:

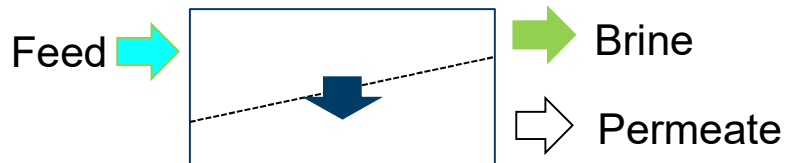
*Literature review and expert inputs on a typical energy requirement to achieve NaCl 20%

**TOYOBO's process is based on NaCl 4% feed solution at a capacity of 100m³/day, operated at the pressure of 7MPa to achieve NaCl 20%

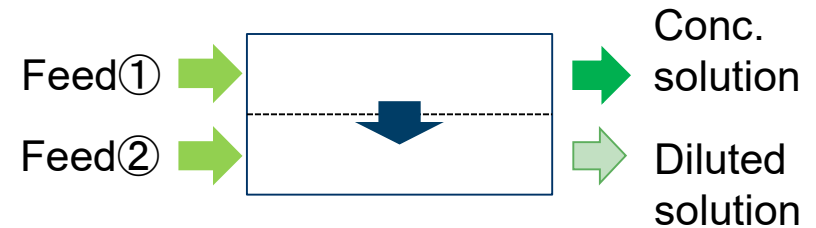
Low-grade waste heat is not included

Required membrane configuration for BC process

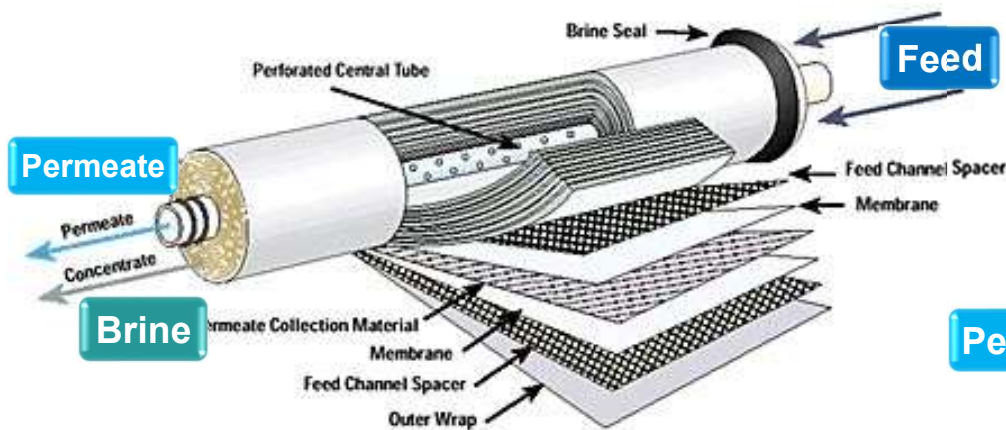
RO



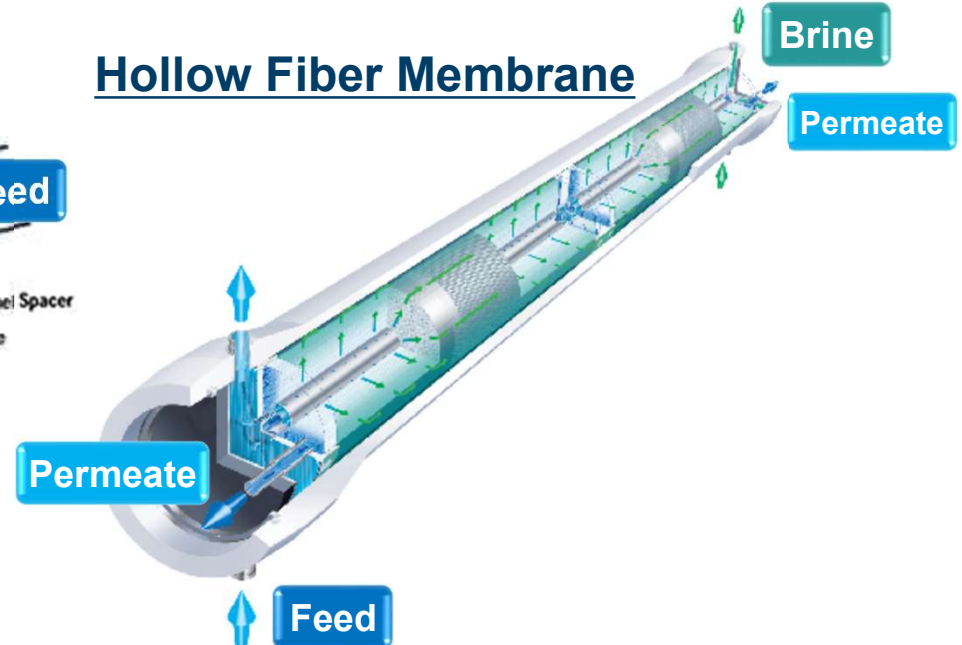
Toyobo's BC



Spiral Wound Membrane



Hollow Fiber Membrane



https://www.ama.org/Reverse_Osmosis_Membrane_Separation.html

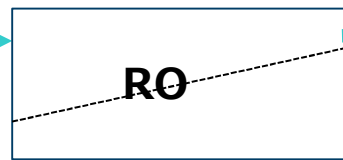
- ✓ Four (4) ports configuration is required for BC process
- ✓ Only hollow fiber configuration is applicable

Examples of Brine Concentration application –1

Increase Seawater RO Recovery

Existing RO process

Seawater (Conc; 4%)
250,000 m³/day

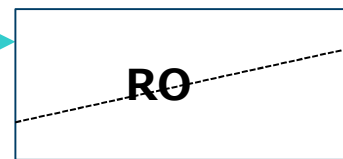


Brine (Conc; 6~7%)
150,000 m³/day

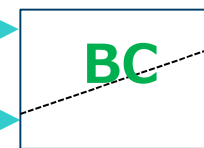
100,000 m³/day

RO combined with BC process

Seawater (Conc; 4%)
250,000 m³/day



6~7%



Brine (Conc; 10%)
100,000 m³/day

100,000 m³/day **+50,000 m³/day**

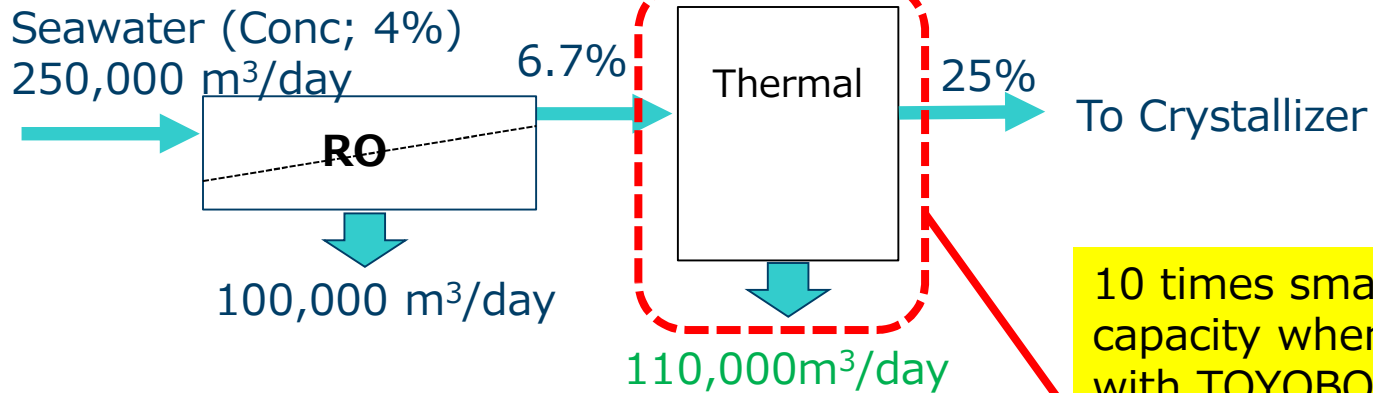
4%

✓ 50% more permeate from RO with the same intake capacity

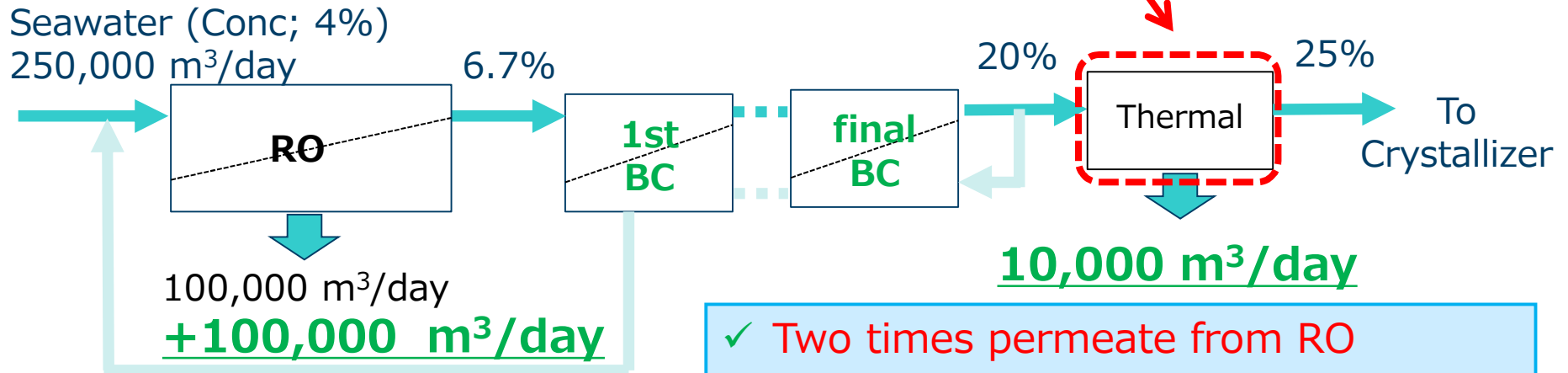
Examples of Brine Concentration Application –2

ZLD (Zero Liquid Discharge) Process

Current process



RO + BC + thermal process



- ✓ Two times permeate from RO
- ✓ Three times less energy consumption

Summary

- 1 Our membrane's unique configuration allows brine concentration up to 20% NaCl using far less energy than conventional thermal and membrane-based technologies
- 2 Our hollow-fiber CTA membranes have unique features of high surface areas and superior chlorine tolerance to enable more rigorous membrane cleaning and stable operation with minimum biofouling
- 3 Toyobo's BC membranes are commercially proven and can be applied for a wide range of industries



Ideas & Chemistry

The information on this presentation is based on the information available as of the day of the presentation.

No part of this presentation may be copied or reproduced without the prior permission of the publishers.

Why is the hollow fiber membrane better for BC?

Spiral Wound

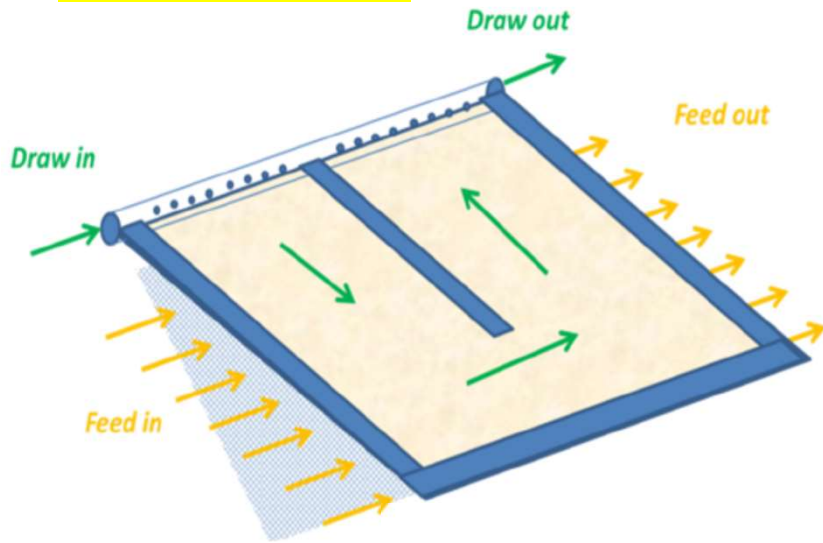
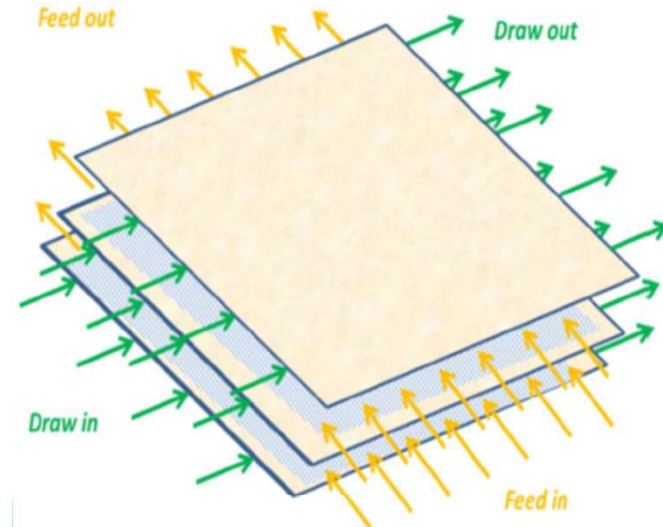
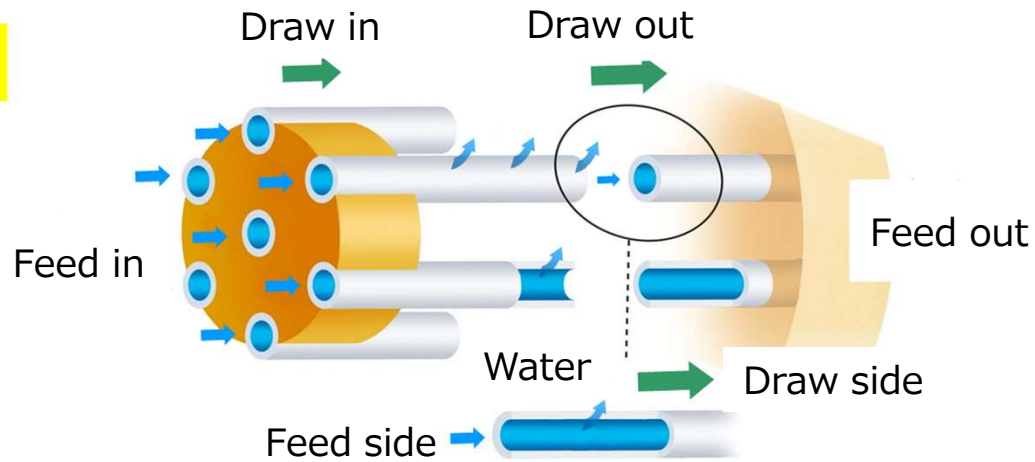


Plate & Frame



Blandin et al., International Forward Osmosis Association World Summit 2015

Hollow fiber



Increase of water production – Gradiant & Sawaco -



Gradiant Partners with Saudi Arabia's SAWACO to Double Production of Fresh Water with Counter-Flow Reverse Osmosis Process

- SAWACO, Saudi Arabia's largest supplier of un-bottled potable water, owns and operates desalination plants that produce over 30,000 cubic meters per day (m^3/d) in the kingdom's western region.
- Increased scarcity of fresh water resources has made it essential to maximize the water production efficiency from the kingdom's desalination and water reclamation plants.
- Gradiant's Counter-Flow Reverse Osmosis (CFROTM) technology can double the fresh water produced by SAWACO's existing desalination operations by effectively extracting fresh water from reverse osmosis (RO) reject brine, concentrating seawater to over 20% salinity.

Zero Liquid Discharge – Hyrec & SWCC -



Saline Water Conversion Corporation (SWCC) Has Signed Mou with Hyrec Technologies Ltd.

Saudi Arabia's Saline Water Conversion Corporation (SWCC) and Hyrec Technologies Ltd. signed a Memorandum of Understanding to deploy Hyrec's Osmotically Assisted Reverse Osmosis (OARO) technology for Zero Liquid Discharge desalination in the Kingdom of Saudi Arabia. The Memorandum of Understanding was signed at the 2019 Saudi Water Forum in Riyadh by Eng. Ali bin Abdulrahman al Hazmi, the Governor of SWCC, and Hyrec's CEO Dr. Basel Abu Sharkh.

SWCC is the world's leading seawater desalination company, producing 4.6 million m³ of fresh water per day in its 28 plants in Saudi Arabia. Hyrec is a pioneer in low energy-consumption membrane systems for high-recovery desalination and salt concentration.

"This is an important milestone for Hyrec," said Dr. Abu Sharkh. "Hyrec's OARO overcomes the limitations of conventional RO. It concentrates brine up to its saturation point and economically extracts salts from seawater and other dilute solutions. Thus, more fresh water is recovered at little additional cost. We look forward to a long and mutually beneficial relationship with SWCC."

Toyobo's Membranes for Reverse Osmosis

- 1 Unique Cellulose Triacetate (CTA) Hollow-Fiber membranes** with over 30 years' experience in membrane water treatment
- 2 One of the Top 3 SWRO membrane suppliers in the GCC** with the largest share of installed capacity (>75%) in Saudi Arabia
- 3 Excellent features to minimise biofouling**, the major operational issue faced by the SWRO industry
- 4 20% Opex savings** compared to PA Spiral-Wound membranes, leading to significant **Life Cycle Cost savings**
- 5 Trusted and repeatedly selected** by renowned customers

Low cost, reliable and stable seawater desalination

1 Proven and one of the most commonly used technology

- Proven technology with numerous installation **in the Middle East**
- **Largest installed capacity in Saudi Arabia**

2 Excellent operational stability

- **Chlorine-tolerant membrane material** for low-cost chlorine injection
- **High membrane surface area** to better tolerate potential fouling

3 Low cost operation

- **Reduced membrane cleaning and replacement**
- **Significant OPEX and Life Cycle Cost savings**

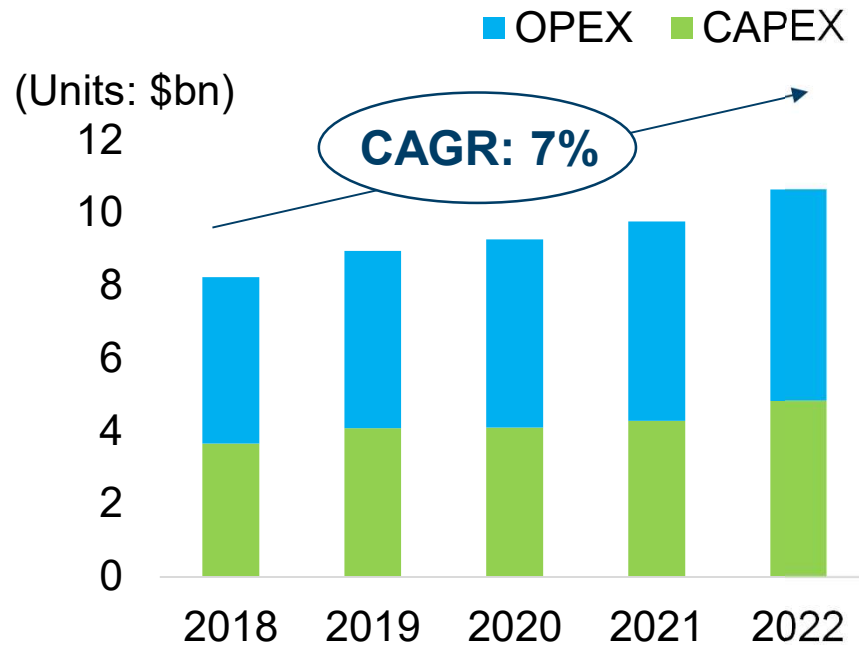
4 High quality service team in Saudi Arabia

- **Local manufacturing and service entity**
- **Full technical services by local team** ensuring stable operations

GCC represents 48% of the fast-growing SWRO market

- Global SWRO market is estimated at \$8 billion today
- Strong annual growth in the next years to exceed \$10 billion in 2022
- The GCC region represents nearly half of the global share

Global SWRO Market (2018 – 2022)



Market share by region (2018)

